Progress In Electromagnetics Research Letters, Vol. 42, 119–127, 2013

A CIRCULARLY POLARIZED COMPACT ANTENNA FOR UHF BAND RFID READER

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Abstract—This paper presents a circularly polarized compact antenna based on the concept of Yagi-Uda antenna. By properly arranging three ring resonators operating at the fundamental mode, a compact Yagi-Uda like antenna is proposed to form directional pattern. This proposed antenna has comparable size with the ring resonator of quarter-wavelength, while the performances are comparable with the conventional microstrip antenna of half-wavelength. To validate the proposed design methodology, an antenna working at UHF radio-frequency identification (RFID) band is benchmarked. Both simulated and measured results are shown for comparison.

1. INTRODUCTION

Microstrip antenna has the features of low profile, light weight and low cost, so it has been widely used in modern wireless communication systems [1]. As a key component of the RFID system, antennas with circular polarization and compact size are preferable for handled RFID reader.

To maintain the antenna performances such as gain and front-to-back ratio, a $\lambda_g/2$ by $\lambda_g/2$ (λ_g is the wavelength in the dielectric) microstrip antenna operating at its fundamental mode must be backed up with a large ground. Apparently, it is unsuitable for UHF RFID reader due to the bulky size. Although different technologies have been proposed to reduce the antenna size [2–7], the size of ground plane is yet to be considered at all. It is well-known that rectangular ring antennas are only quarter-wavelength when operating at the fundamental mode [8], thus it is potential candidate for the RFID reader. Unfortunately, large ground plane is still required [9].

Received 15 July 2013, Accepted 28 August 2013, Scheduled 4 September 2013
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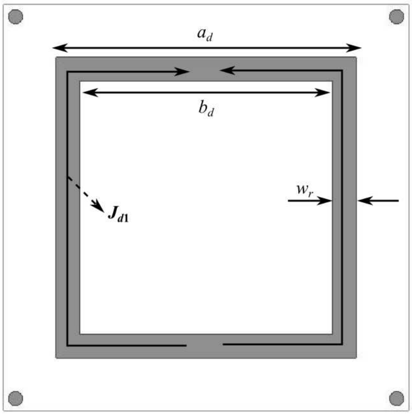
To radiate the circularly polarized wave, there are always two methods. Firstly, two orthogonal modes can be excited by the perturbation method [8, 10–14]. However, the axial ratio (AR) bandwidth is very narrow. Secondly, an addition power divider or coupler can be employed to feed the antenna at two or four ports with the same amplitude and 90° phase difference [9, 15–22]. The AR bandwidth can cover the impedance bandwidth, while the antenna size will increase because of the additional feeding network.

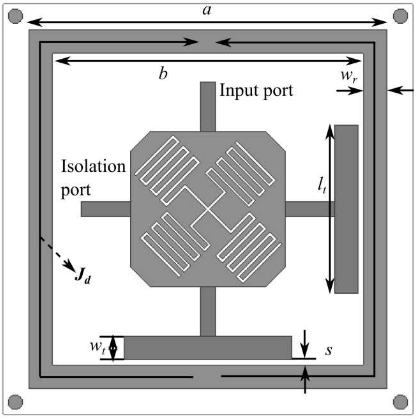
To tackle above issues, a novel circularly polarized compact antenna is developed in this paper. The ground plane is replaced by a meandered ring reflector with size equal to the antenna. Furthermore, another ring is placed on top of the antenna to serve as a director. A hybrid patch coupler is integrated inside the rectangular ring antenna to form the circular polarization. With this arrangement, directional pattern is formed with the compact size of $\lambda_g/4 \times \lambda_g/4$ in the horizontal plane.

2. THE PROPOSED ANTENNA DESIGN

The geometry illustration of the proposed antenna is shown in Fig. 1. It is composed of three rings with different sizes. The current distributions ($\mathbf{J_d}$, $\mathbf{J_{d1}}$ and $\mathbf{J_r}$) on different rings are also presented in Fig. 1. It is noted that currents on these three rings have the same distributions as those on the dipole antenna, as shown in Fig. 2. Therefore, a Yagi-Uda like antenna can be facilitated by arranging three rings in the vertical configuration. Follow the conventional Yagi-Uda antenna, three different rings are named as director, driven element and reflector respectively in this paper.



(a)



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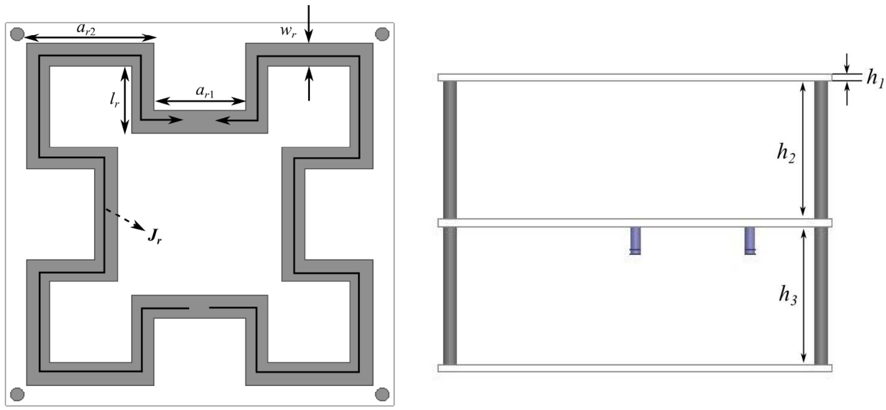


(c) (d)

Figure 1. Configuration of the proposed antenna. (a) Director. (b) Driven element. (c) Reflector. (d) Cross view.

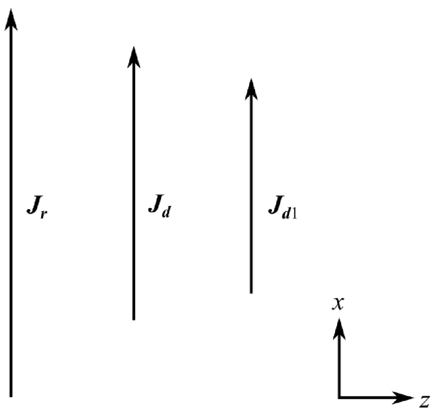


Figure 2. Working principle of the proposed antenna.

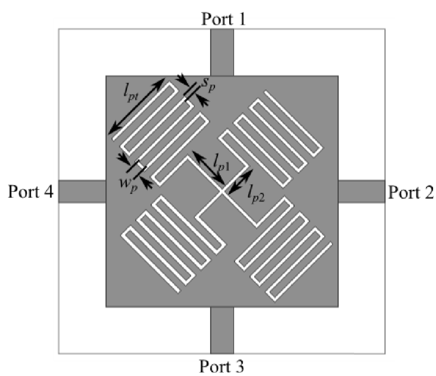


Figure 3. Configuration of the coupler.

When rectangular ring antenna operated at its fundamental mode, the input impedance will be very high if it is fed by coaxial cable directly. So the parallel coupling microstrip line is employed to feed the antenna and it can be considered as a matching network. By tuning values of l_t, w_t and s, the proposed antenna can be easily matched to 50 ohms.

To radiate circularly polarized wave, following the guideline in [23], a hybrid patch coupler is designed, as shown in Fig. 3. Then the designed coupler is integrated into the driven element without increasing the antenna size [9]. By tuning the dimension of director (b_d and a_d), reflector (l_r), or the distance among them (h_2 and h_3), a directional pattern with circular polarization can be easily and conveniently obtained. The antenna performances such as gain, front to back ratio and the bandwidth is related with the above parameters, so the proposed antenna can be considered as an adjustable antenna either.

In our design process, the proposed antenna is simulated with the commercial full wave solver HFSS. The finally optimized dimensions are shown in Table 1. The dimension of the proposed antenna in the horizontal plane is $\lambda_g/4 \times \lambda_g/4$. Fig. 4 presents the simulated $|S_{11}|$. It is observed that the impedance bandwidth ($|S_{11}| < -10\,\text{dB}$) is from 0.855 to 1.05 GHz, which covers the entire UHF RFID band. However, the radiation bandwidth is not as wide as the impedance bandwidth. As shown in Fig. 5, $|S_{21}|$ defines the power that transmitted to

Table 1. Optimized dimensions of the proposed antenna (unit: mm).

Dimension	value	Dimension	value
a_d	63	a_{r1}	20
b_d	53	a_{r2}	28
a	74.5	w_r	5
b	64.5	h_1	1.6
l_t	35	h_2	30
w_t	5	h_3	30
s	1	l_r	15
w_p	1	l_{pt}	11.4
s_p	0.5	l_{p1}	6.75
l_{p2}	5		

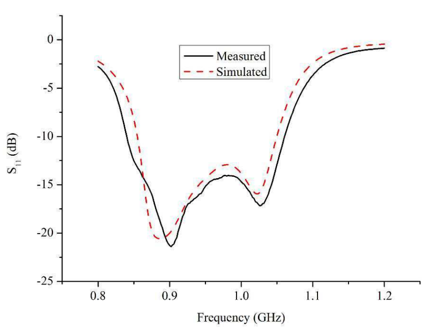


Figure 4. Simulated and measured S_{11} of the proposed antenna.

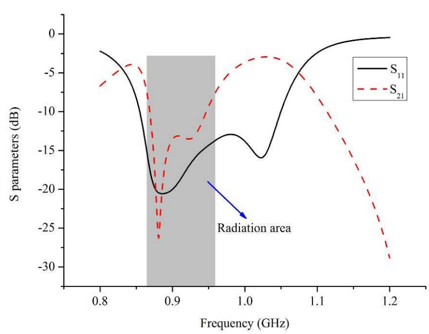
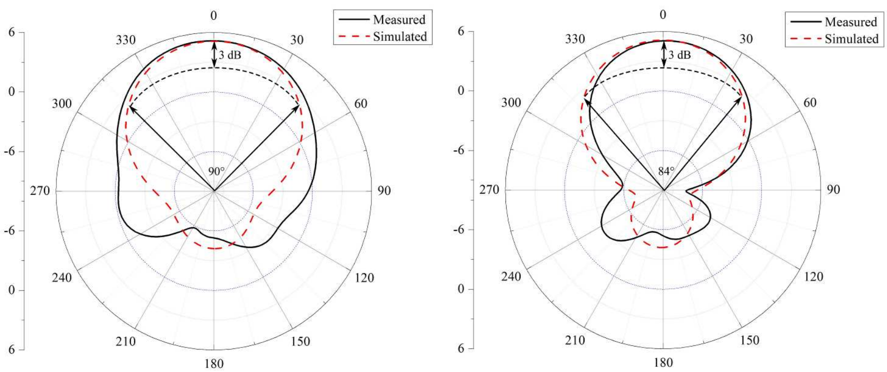


Figure 5. Simulated S parameters of the proposed antenna.

the isolation port from the input port of the hybrid patch coupler. Apparently, it is found the energy is absorbed by the matching load terminated to the isolation port of the hybrid patch coupler rather than radiation outside the operating band. So the operating bandwidth for the proposed antenna should be 0.86 to 0.93 GHz rather than 0.855 to 1.05 GHz. In Fig. 6, simulated radiation pattern at 915 MHz is shown. Obviously, directional pattern is formed with our proposed configuration. The beam width in Phi = 0° plane is 90°, while it is 84° in Phi = 90° plane. As it can be seen in Fig. 7, the simulated maximum gain is 5.2 dBi, while the minimum one is 1.6 dBi in the band of 0.86 to 0.96 GHz. Also, the gain larger than 4 dBi is from 0.86 to 0.93 GHz. Fig. 8 depicts the simulated axial ratio (AR) of the proposed antenna, the AR bandwidth (AR < 3 dB) is from 0.865 to 0.96 GHz, which is



(a) (b)

Figure 6. Simulated and measured radiation pattern of the proposed antenna. (a) Phi = 0°. (b) Phi = 90°.

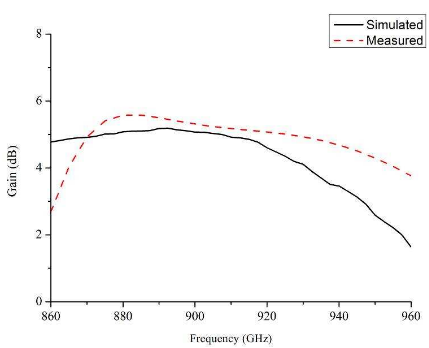


Figure 7. Simulated and measured gain of the proposed antenna.

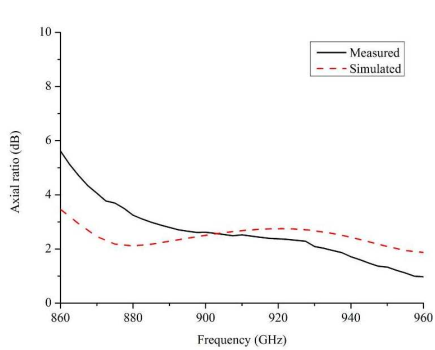


Figure 8. Simulated and measured axial ratio of the proposed antenna.

almost covers the entire UHF RFID band.

A comprehensive comparison among the performances of the proposed design and the existing antennas is performed in Table 2. The proposed antenna has the following advantages:

a) The horizontal size of the proposed antenna is much smaller than the reported antennas.
b) Performances of the proposed antenna can be tuned by changing the distance (h_2 and h_3) among rings, so the proposed antenna can be considered as an adjustable antenna.
c) Easy to fabricate with low cost.

However, it is found that the proposed antenna have the disadvantages of high profile and low gain, so there is a compromise between the antenna size and antenna performances, which is determined by the specified applications.

Table 2. Performance comparison with the referenced work.

Ref.	Operating frequency band		Physical size	Gain (dBi)
	Impedance band width	Axial ratio band width		
[9]	902 MHz–920 MHz	902 MHz–920 MHz	150 mm × 150 mm × 20 mm	> 5.3
[13]	880 MHz–110 MHz	901 MHz–930 MHz	150 mm ∗ 150 mm ∗ 34 mm	> 7
[21]	815 MHz–993 MHz	860 MHz–960 MHz	260 mm ∗ 260 mm ∗ 32.5 mm	> 8.5
[22]	818 MHz–964 MHz	818 MHz–964 MHz	250 mm ∗ 250 mm ∗ 35 mm	> 8.3
This work	860 MHz–930 MHz	865 MHz–960 MHz	85 mm ∗ 85 mm ∗ 60 mm	> 4

3. EXPERIMENTAL RESULTS AND DISCUSSION

To experimentally verify the proposed design, a prototype is fabricated and measured. A photograph of the fabricated antenna is shown in Fig. 9. Measured $|S_{11}|$ is shown in Fig. 4, good agreements are observed between the simulated and measured results. Fig. 6 shows the measured radiation pattern, it is found that there is a discrepancy between the simulated and measured one in the back lobe area. It is mainly caused by the measurement error. In our measurement scenario, Satimo starlab D is employed to measure the radiation pattern of the antenna. However, there is no probe under the antenna and the back lobe is thus estimated by the approximation method for this system. The measured gain is shown in Fig. 7, only slight discrepancy between the simulated and measured results is observed,

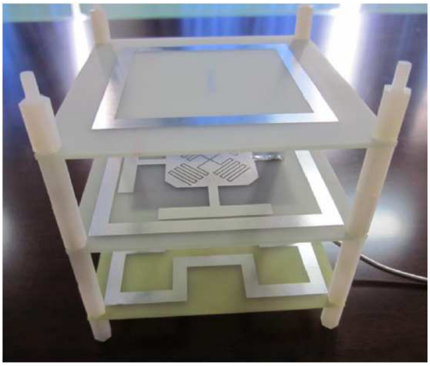


Figure 9. Photograph of fabricated prototype.

which is caused by the unstable characteristics of the cheap FR4 substrate and the inaccurate thickness (h_2 and h_3) of air substrate among rings.

As shown in Fig. 8, there is a discrepancy between the simulated AR and measured one. As we know, AR is related to the amplitude balance and phase difference provided by the coupler. However, both of them are affected by the unstable characteristics of the cheap FR4 substrate, which means the amplitude balance and phase difference could not be guaranteed. In addition, the inaccurate thickness (h_2 and h_3) of air substrate among rings and the feeding cables also affect the AR.

4. CONCLUSION

To maintain the antenna performance with compact size, a novel antenna is designed using Yagi-Uda configuration. The impedance and AR bandwidth of the proposed antenna almost cover the entire UHF band, whereas the gain of the antenna degrades significantly in the high frequency region of the UHF band. The proposed antenna has the features of easy design, low cost and light weight. It will be a good candidate for mass production.

ACKNOWLEDGMENT

This work was supported in part by the Innovation Research Funds of China Academy Space Technology (Xi'an), in part by the Fundamental Research Funds for the Central Universities, and in part by the National Natural Science Foundation of China (No. 11176007 and No. 61001029).

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